64 Alternative Energy III—Wind Energy

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INTRODUCTION

Extracting energy from the wind is not a new idea by any means. Wind power has been used for over a 1000 years and prior to the industrial revolution, wind mills were a key source of power for many decades if not millennia. However, more recently, the oil crisis of the 1970s, awareness of climate change issues, peak oil, and energy security concerns have all increased the interest in renewable energy sources. Although not the only renewable source, wind power has huge potential and is also very cost effective. As a result, the last 25 years have seen a rapid growth in the generation of grid connected electrical energy from the wind.

The global wind industry has achieved 25% year on year growth and at the end of 2009 represented 160 GW of installed capacity and is predicted to exceed 200 GW in 2010.

Commercial wind turbines have grown from 20 m diameter, 100 kW turbines to 120 m diameter 5 MW machines.

Although the turbines are now generally three bladed, pitch regulated, upwind machines with variable speed drives, turbine design continues to evolve as manufacturers strive to reduce the cost of energy and to meet new challenges such as the offshore environment and grid integration issues.

The turbine supply industry has changed from one driven by "pioneers" to a mature sector with global players such as GE, MHI, Siemens as well as the large wind energy companies such as Vestas, Gamesa, Enercon, Suzlon.

Utilities are now very active in the wind energy sector in addition to the independent power producers and developers who delivered the earlier growth of wind energy. The larger owners are now operating portfolios of wind farms, often from centralized 24/7 control rooms.

As wind energy penetration levels on grid systems increase, transmission system operators have become more interested and involved with the electrical aspects of wind farms.

Supervisory control and data acquisition (SCADA) systems within wind farms and portfolios of wind farms are a key tool that allows the safe and efficient operation of wind energy plant.

They are also responsible for implementing a number of control strategies to ensure that the wind farm operates within its design constraints and any limits imposed by the grid connection. They also implement control strategies to manage various environmental constraints such as noise, flicker, and avian issues.

The data they collect are also crucial for assessing the performance of the plant, both against turbine suppliers warranted performance and against the original budgets for the wind farm.

In this chapter, we will explore: the basic principles of wind energy and size of the global resource, the components that make up a wind farm, the project lifecycle for a wind farm, and SCADA Systems within wind farms and wind farm portfolios.

WIND ENERGY OVERVIEW

Principles

Wind is the flow of air between regions of different atmospheric pressure, which in turn is caused by differential heating of the atmosphere so ultimately, the energy source is the sun.

As we have all experienced, wind is a variable resource with short-term variations (gusts) and longer term variations as weather systems move through an area. Some areas show strong diurnal variations, particularly coastal areas and generally wind and weather patterns show seasonal variations. There are also longer term patterns in the wind due to factors such as El Niño.

Many regions have very specific wind systems which arise from local geographic features, especially mountain passes in coastal areas.

Forecasting what the wind and weather will be over a time horizon of days or weeks is an activity to which much effort is applied and whose results carry a degree of uncertainty. However, over periods of months and years, the average wind speeds and distributions are predictable with much higher confidence levels.

Wind flow and turbulence is very much three-dimensional with significant vertical components (upflow) as well as horizontal speed and direction. They are greatly affected by the topology and type of ground cover that the wind flows over, with speeds increasing over and around hills and turbulence affected by steepness of slopes and types of vegetation.

The speed and direction of the wind also varies with height above the ground (shear and veer).

Wind speed distributions typically have a Weibull distribution. An example of a typical annual wind speed distribution is shown in Figure 64.1.

Wind turbines extract energy from the wind by slowing it down. The potential power available in the wind is given by

$$P = 0.5 * \rho A V^3 \tag{64.1}$$

where

P is the power (W)
ρ is the air density (kg/m^3)
A is the swept area of rotor (m^2)
V is the wind speed (m/s)

However, they cannot stop the wind speed completely as there would be nowhere for the stopped wind to go. There is therefore a theoretical limit to the aerodynamic efficiency of a wind turbine of 59.3%, known as the Betz limit. The power extracted from the wind by a turbine is therefore

$$P = 0.5 * \rho A V^3 C_p \tag{64.2}$$

where C_p is the coefficient of power.

For a given blade design, the coefficient of power is a function of the tip speed ratio (the ratio of the wind speed and the speed of the tip of the turbine blade) and the pitch angle. For a given pitch angle, there is an optimum value of tip speed ratio.

From these equations, we can see that the power available increases with the cube of the wind speed. Although the power available in very high wind speeds increases dramatically due to this cube law, the frequency of these wind speeds is low. The energy that could be extracted from high winds is therefore low and so it is not worth designing turbines that can extract all available power in all wind speeds. Turbines therefore have a maximum power rating and as wind speeds increase above the level that produces this rated power, they have some kind of power limitation mechanism to limit the power captured by the wind. Typically this is by pitching the blades (active control) but some turbines have blades that are designed to stall in higher winds (passive control). The rated wind speed of a wind turbine is typically around 12 m/s but this depends on the turbine type and model—some models are optimized for lower wind speed sites.

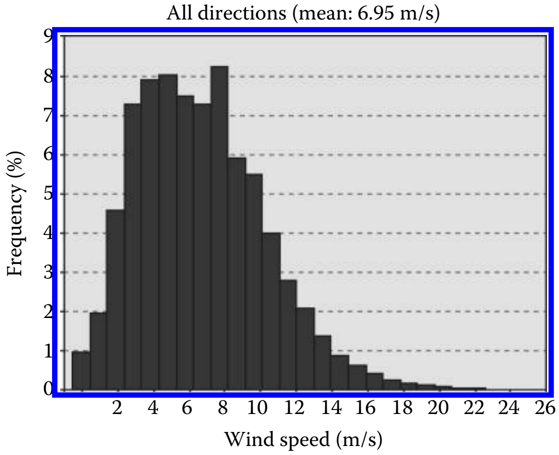


FIG. 64.1
Typical annual wind speed distribution.

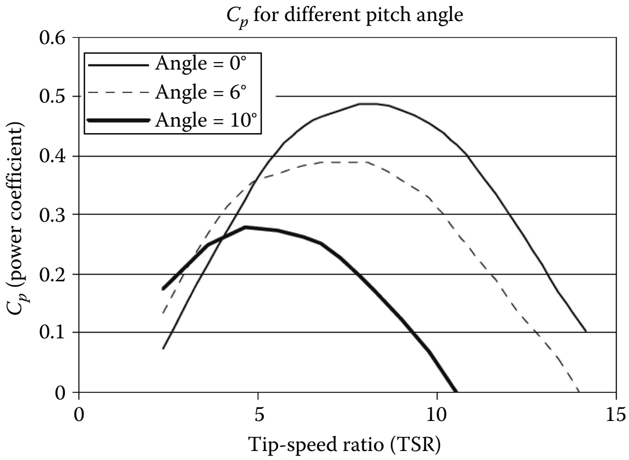


FIG. 64.2
Pitch angle for optimized operations of wind turbines.

From the C_p curves, in Figure 64.2, we can see that there will be a pitch angle that gives a maximum C_p and that to optimize energy capture the turbine should run with that pitch angle and at the tip speed ratio that corresponds to that maximum. For wind speeds below rated, therefore, the turbine would ideally run at a fixed pitch angle and a variable rotor speed, with the rotor speed proportional to the wind speed. Historically, most early turbines were fixed speed, using induction generators. However, the reduced cost of power electronics and variable speed drives together with their improved reactive power capabilities has meant that nearly all new turbines are variable speed.

The turbines also only carry on generating up to an upper cut-out wind speed, typically 25 m/s. The energy benefit of extending the operating range above this cut-out wind speed does not justify the increase in machine cost of dealing with the increasing loads.

The combination of available power, aerodynamic efficiencies, mechanical efficiencies electrical efficiencies and operating envelope result in a power curve for the turbine as illustrated in Figure 64.3:

From the equation for available power, we can also see that the power is proportional to the air density, which in turn depends on the air temperature and pressure. A power curve therefore applies to a specific air density. When using power curves to predict resource or when using measurements to produce power curves it is therefore essential to make corrections for air density.

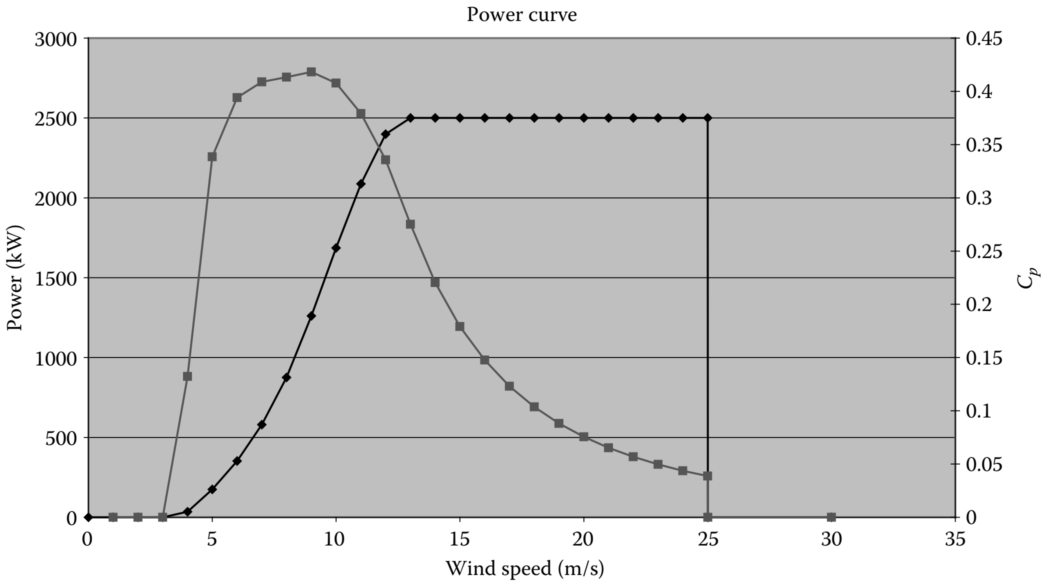


FIG. 64.3

Efficiency and power curve in wind turbines.

For an individual turbine, the power curve can be combined with a wind speed distribution to create an expected energy output per year.

The energy produced by a turbine over a period of time divided by what it would have produced if it had run continuously at its rated power is known as its capacity factor. The capacity factor that is achieved by turbines depends on the turbine characteristics, the windier the site, and the reliability of the turbine. On a reasonable site, a capacity factor of 25%–30% would be expected.

When assessing potential wind farm sites, a meteorological mast is erected and measurements are taken for a period of 6 months to a year. These will include wind speed and direction at the turbine hub height, temperature, pressure, and usually wind speed and directions at other heights. These readings are then correlated to a nearby meteorological station which has long-term data. The long-term data are combined with the correlation to produce a prediction of the long-term wind speed characteristics for the site meteorological mast location.

Data is collected and stored in the form of 10 min statistics (mean, maximum, minimum, and the standard deviation). A 10 min averaging period is used as it falls between a gap in the frequency spectrum of the wind—it is long enough to average out turbulence and short enough to track changes due to weather patterns. Over a 10 min period, good correlation is observed between a wind speed readings at a point and the power produced by a turbine. As a consequence, all analysis of wind turbine performance is based on 10 min statistics.

The standard deviation of the wind over a 10 min period divided by the average wind speed for that period is known as the turbulence intensity and is used in assessing site conditions.

The long-term mean that is calculated applies to one location on the wind farm. When looking at the performance of a wind farm, the wind flow over the whole site must be modeled to provide a wind speed distribution at each turbine location. Turbines also produce wakes. Downwind of the rotor, the wind speed is slowed down and the turbulence increased. As the wake moves downstream from the turbine, the air mixes with the adjacent undisturbed air. The wake spreads out the further it gets from the turbine and drops when the wind speed reduces. The exact profile of the wake depends on a number of factors, including the turbulence but typically becomes insignificant after 5–10 turbine diameters. This is illustrated in Figure 64.4.

To assess the output from a wind farm, each direction sector needs to be considered in turn. Wakes are modeled for the wind direction and combined with the wind flow modeling over the site to produce a wind speed distribution at each turbine location for that wind direction. This can then be combined with the power curve to give an energy estimate for each turbine for that sector. This process is repeated for each sector to give the overall expected output.

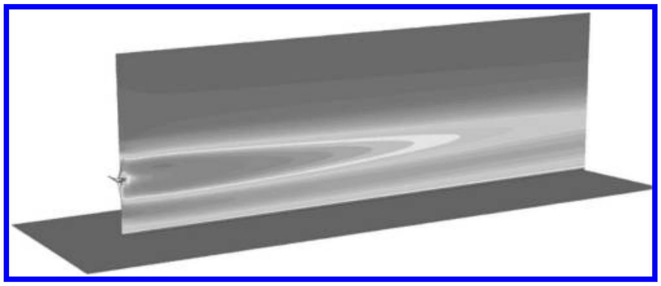


FIG. 64.4

Typical profile of wake in wind turbines.

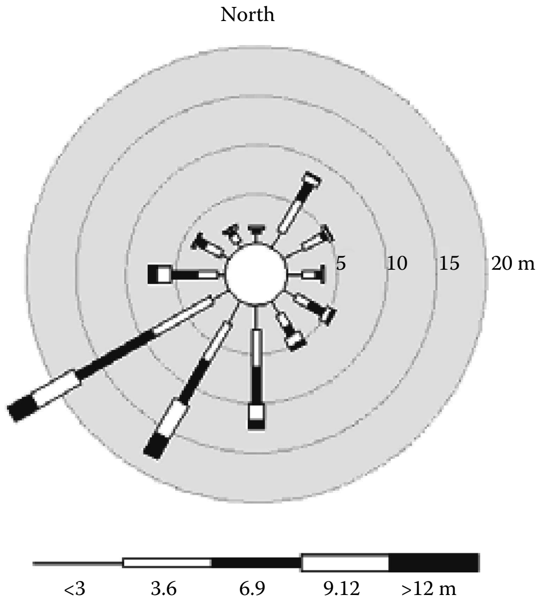


FIG. 64.5
Wind rose plot relating wind speed and direction.

The wind direction distribution is therefore just as important as the wind direction itself when designing the layout of a wind farm. The wind speed and direction information is usually summarized in a wind rose plot (Figure 64.5).

Size of Industry and Global Potential

The global wind industry represented 160 GW of installed capacity at the end of 2009 and is predicted to exceed 200 GW in 2010. Assuming an average turbine size of 2 MW, the number of installed turbines will be in excess of 80,000 in 2010. In 2009, global turnover of the wind industry was 70 billion US$ and employed over 5,00,000 people.

Studies have been carried out in various regions to estimate the potential of wind energy. These vary in level of detail and the constraints that are applied so it is difficult to put a figure on what the maximum global potential could be. However, it seems clear that for some time into the future, it will not be the available resource that is the limiting factor for wind energy.

The World Wind Energy Association predicts that global wind energy installed capacity will continue to double every 3 years and that an installed capacity of 1900 GW can be reached by 2020.

As the industry grows, new technical challenges will have to be met. Turbines are already being deployed offshore. Transmission systems will need to be modified and forecasting/scheduling will need improved.

Turbines

At their simplest, a modern wind turbine consists of a rotor which captures the aerodynamic power and drives a generator to produce electrical power.

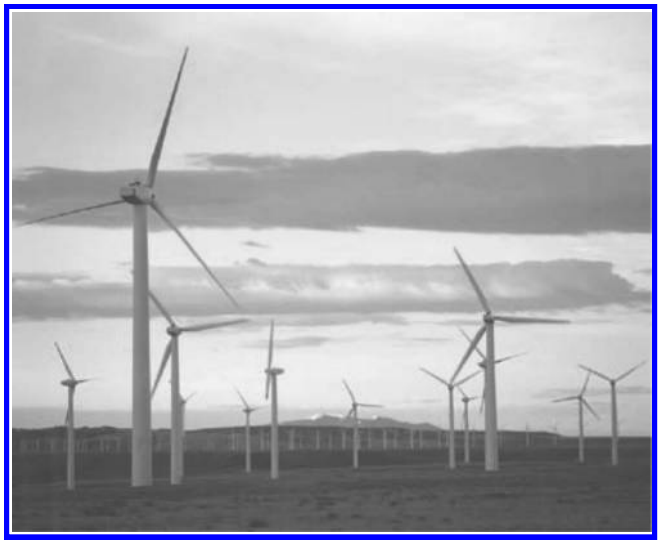


FIG. 64.6
Typical wind farm arrangement using three-blade turbines.

The evolution of wind turbine design has seen many different formats of turbines and novel concepts. There have been vertical axis and horizontal axis turbines, various numbers of blades, pitch regulation and stall regulation, fixed speed and variable speed designs. Generators have been induction, synchronous, permanent magnet.

However, most current wind turbines consist of a three-bladed upwind rotors mounted to a nacelle on top of a tubular steel tower, as in Figure 64.6. The following is a general description of a typical modern turbine.

The blades are attached to a hub via pitch bearings and have either hydraulic or electrical pitch actuators on each blade. Each blade can pitch individually and has a backup energy store to allow blades to feather in an emergency. The nacelle consists of a structural bedplate which supports the low-speed shaft via bearings, the gearbox (if there is one) and the generator. Low-speed bearings may be integral to the gearbox. The nacelle may also contain a transformer on larger turbines. The bedplate is attached to the tower top via a yaw bearing and a yaw drive allows the whole nacelle and rotor to rotate into the wind. Power is transmitted down the tower via cables, which allows a number of turns before the turbine shuts down and unwind its cables.

The generators take a variety of forms from induction generators, wound rotor induction generators, permanent magnet generators. Some are low-speed direct drive devices with no gearbox.

Most turbines now have variable speed drives, either partially or fully rated. As well as allowing variable speed operation to optimize energy capture, they allow the torque loads to be controlled and limited. They also provide a high degree of flexibility for integration with wind farm electrical systems.

Access to the nacelle is by means of a ladder within the tower. As towers are starting to exceed 100 m in height, many are now fitted with lifts.

The turbines have sensors to detect wind speed and direction and each has its own controller which allows it to run autonomously. There is usually a local HMI at the turbine base for use by operations and maintenance crew.

The controller monitors the environmental conditions and decides when to start and stop the turbine and keeps it facing into the wind. When running, the controller regulates the drive torque and pitch angles to achieve the required speed and power profiles.

The controllers provide a communications interface for a SCADA system and these allow access to real-time values, alarm conditions, and commands. There are suitable interlocks to disable remote control if there is crew at the turbine. The controllers typically have up to 200 analog signals per turbine and several hundred possible alarms.

The controllers also allow the turbines to be operated at a reduced real power set-point when required to do so due to external constraints.

Once released to run, the turbines will run unattended unless they detect a condition that requires manual intervention. Most alarm conditions can be investigated remotely and reset remotely. Alarms are typically acknowledged “en masse” for a turbine rather than individually.

WIND FARMS

Wind Farms and Balance of Plant

Although development models vary in different countries, wind turbines are mostly installed in groups, or wind farms. The turbines are only part of the wind farm, and various other elements are generally referred to as the balance of plant. In order to deliver power to the grid, it is necessary to provide foundations, access roads, power and communications cabling, transformers, and grid connection switchgear at a minimum.

Most wind farms have a medium voltage (MV) distribution system around the site, with a number of electrical circuits. These site distribution networks are usually buried cable. There is usually a transformer at each turbine to reduce the voltage from MV to low voltage. These may be adjacent to the turbine, inside the tower base or on some larger turbines in the nacelle.

Communications circuits and cabling usually follow the electrical circuits.

A site substation at the grid connection point will usually have a high voltage (HV) transformer, revenue metering, switchgear, and power factor correction equipment.

On larger wind farms, there will usually be a control room and a facility for holding spares. The site SCADA system is usually located in the control room.

Meteorological Masts

Most wind farms will have one or more permanent meteorological mast. These are not always in the same locations as the original assessment masts. If this is the case, it is advantageous to have periods of overlapping data collection from both devices so that correlations can be calculated between the two locations. Prior to construction it is also common to have a period of data collection from the permanent mast and a temporary mast at an adjacent turbine location. This allows correlations to be calculated which enable site calibration of turbine performance once they are built.

As mentioned, wind speed and direction are measured at hub height at least and usually at other heights as well.

Masts are usually guyed lattice towers although some are free standing. As the hub height of turbines increases, installing and maintaining masts with hub height anemometry is becoming increasingly challenging.

The permanent masts are usually powered from the wind farm power network and connect to its communications network. However, they use low-power loggers and have battery backup with solar panels so that they can continue to collect and store data in the event of power loss. This is essential so that lost production for periods of grid outages can be estimated automatically.

The loggers used are quite specialized for environmental monitoring and many have been developed specifically for the wind industry. They typically have proprietary communications interfaces and data formats although some can provide real-time interfaces through standard protocols such as Modbus.

Substations and Grid Interfaces

The substations are usually the point of interconnect to the utility grid. On the grid side, there will be revenue meters in addition to the required switchgear and protection. There is usually a step-down transformer to reduce the HV grid to the wind farms MV electrical system. On larger wind farms there may be more than one transformer. From the transformer, there are a number of electrical circuits which feed radially.

Wind farms have to comply with increasingly stringent grid codes. These obviously vary from region to region and particular projects may need to meet location specific requirements.

Projects are likely to have to meet reactive power constraints, either to operate within specified power factors or to set reactive power as a function of voltage. Many modern turbines have reactive power control capabilities through their variable speed drives that can be used to contribute to meeting these requirements, or in some cases, entirely meeting the requirements.

Most substations will have some level of controllable reactive power capabilities, either in the form of switched capacitor banks or static volt ampere reactive compensators, depending on the bandwidth and resolution of control required.

There is usually a backup power system at the substation to provide power to the central equipment during periods of power outages.

A substation controller usually co-ordinates the substation equipment and implement the required substation logic and control.

At a wind-farm level, the grid operator may also require the ability to limit the real power output of the project (curtailment) and impose limits on the rate of change of power as the wind farm starts up and shuts down.

Typically, there is a requirement to provide information about the wind farm to the grid operator and to also receive control signals from them. This communication interface may be provided by the substation controller or an associated remote terminal unit (RTU). A communication interface is also provided for the wind farm SCADA system.

The substation controller and RTUs tend to be standard substation equipment and provide standard interfaces such as distributed network protocol (DNP) and Modbus.

Communications Infrastructure

Early wind farms used serial communications over copper twisted pairs cables, radio or fiber optics.

For copper solutions, the distances involved on rows of turbines often exceeded what was achievable by standard multi-drop solutions such as RS485 and so many suppliers used proprietary solutions. The main drawback of early copper systems was their susceptibility to interference and being damaged from voltage transients, so they were often unreliable.

Early serial fiber solutions used daisy-chained communications loops. These solutions were free from transient-related issues but still generally relied on proprietary hardware. They also had the disadvantage that loss of power to any of the turbines in the loop meant loss of communications to all turbines in the loop.

Serial radios were deployed successfully but usually as point to point links to cover uncabled areas. Problems with mounting antennas on turbine towers and the variation of performance in different weather conditions and different turbine orientations complicated their use though.

Radio Ethernet has been used in wind farms but has not proved popular apart from implementing point to point links where no cabled route is possible.

More recently, fiber-optic based Ethernet has become standard in wind farms. The distances involved are too long for copper-based solutions. These networks are usually a mixture of single mode and multimode fiber. Along rows of turbines, distances between adjacent turbines are typically less than a kilometer and so multi-mode fiber can be used. Each row is usually arranged in a redundant ring with one set of cores picking up alternate turbines along the row and another pair of cores picking up the other turbines. More information can be found on fiber networks in Chapters 33 and 34.

Each row is then connected back to the control room to a pair of redundant switches. This return leg is often longer than 2 km and so is usually single mode fiber.

As all wind farms have a power distribution network, the fiber cables can usually be laid in the same trenches. For offshore wind farms, the fiber communications cores are usually integral with the power cable.

For communications from the wind farm to the outside world, early wind farms relied on public switched data network or integrated services digital networks dial-up connections. Larger projects had leased lines. However, it is generally possible to have at least asymmetric digital subscriber line connections to most wind farms now and where this is not possible, satellite internet access is now a viable option. Many large wind farms have one or more T1 lines.

Wind farm SCADA systems are subject to security requirements in many countries and in such cases, virtual private networks are employed to limit access to the systems.

Wind Farm Control Issues

In addition to electrical control requirements within a wind farm, there are often other constraints on operation.

Where sites have a strong prevailing wind direction, the site layout will consist of rows of turbines perpendicular to the prevailing wind direction. These rows are sufficiently separated to minimize wake effects from the prevailing wind direction and the turbines are tightly spaced within the rows as the wind will rarely blow along the rows. However, when it does, the close spacing of the turbines along the row can cause problems with turbulence and wakes. To avoid these problems, it is usual to shutdown alternate turbines along a row when the wind is above a certain wind speed and is blowing along the row. This is known as columnar wind control. As only knowledge of the wind speed and direction is required for this, it can be implemented in the turbine controller. This requires turbine specific configuration though and so it is more often implemented by the wind farm SCADA system.

Often, when designing a wind farm layout, conditions at particular locations for particular wind speeds and directions may exceed the design specification for a turbine. This can be turbulence levels or up-flow, typically associated with steep slopes. This can result in operational constraints where particular turbines are shutdown for specific wind conditions. This is a more generalized case of columnar wind control.

As well as engineering-based constraints, there are also environmental considerations when operating a wind farm. There has been much publicity about aspects of wind farms such as noise, shadow flicker, and effect on wildlife such as birds and bats. These result in very emotive debates between wind farm developers and wind farm detractors but from a technical perspective there are a number of mitigating steps that can be taken. Every effort is made during the wind farm design to minimize any adverse effect on local residents and wildlife. However, it is impractical to design a wind farm to have absolutely no effect on anything in all conditions.

There have been turbines in the past that have certainly been noisy but modern turbine designs pay great attention to minimizing sound output. Although they are obviously not completely silent, most people who have seen a modern turbine from close quarters are surprised at how little sound they emit. The sound detectable at a habitation will depend primarily on how close the wind turbines are, how windy it is and what direction the wind is coming from. How noticeable the sound is can also be dependent on time of day. By stopping particular turbines for certain combinations of wind speed and direction and time of day, the sound levels at nearby habitation can be kept within acceptable levels without impacting too heavily on the wind farm production.

Shadow flicker, the chopping of direct sunlight by the rotating blades, is another environmental impact. The locations affected by shadow flicker will depend on the position of the sun and the orientation of the turbines (in effect the wind direction). Again, by restricting turbine operation for particular times of day and wind directions, and of course when it is sunny, shadow flicker can be avoided at sensitive locations.

Turbines are also potential threat to birds and bats. Some sites will have to be avoided altogether but there are many locations where the risk only occurs relatively infrequently and so measures can be taken to reduce the risk to acceptable levels without impacting production adversely. For sites which could affect migratory birds, avian radar systems have been employed to detect when bird flocks are approaching so that the wind farm can be shutdown. Bats tend to fly at dawn and dusk and only in lower winds so shutting down turbines in these conditions can manage the risk of adverse affects on bats.

These various curtailment strategies are usually managed by the wind farm SCADA system. As well as implementing the actual control, the SCADA systems also need to keep track of when turbines are stopped and why so that the owners and operators of the wind farms can assess the impact on production.

Project Lifecycles, Contracts, and Key Performance Index

A wind farm project starts by developers identifying potential sites. Areas that are sufficiently windy can be identified from wind atlases. Various other constraints are considered such as suitable grid connections, transport infrastructure, current land use, proximity of residents, planning constraints, etc.

As a project progresses, detailed wind speed measurements are made and wind farm layouts are designed. Agreements with landowners and power purchase contracts are negotiated. As project viability increases, planning applications are made and financing options explored.

For commercial projects, the usual arrangement is for the wind farm to lease land from the landowner, either for a fixed rent or for a percentage of the turbines revenue.

Developers will often sell on the projects at various stages of the development process, the value of the project obviously increasing at each stage.

In order to raise finance for the actual construction of the wind farm, investors will require confidence in not only the costs associated with the project but also the projected revenue stream. The revenue depends on the performance of the turbines and wind farm infrastructure and also on the wind resource. A good long-term estimate of the wind speed distribution of the project and good modeling of the wind flow over the site and the wake interactions is therefore essential. The resulting budget production is the key benchmark against which the operating project will be compared.

When a project is constructed, there is usually a turbine supplier, civil engineering contractor, an electrical contractor, and a SCADA system supplier. Often, the turbine supplier will take responsibility for all aspects of the project and deliver it on a turnkey basis.

The turbine supplier will usually be expected to provide both an availability guarantee and a performance guarantee for the warranty period. That is, they will need to guarantee that the turbine is available for operation for a stated percentage of the time (typically 95%) and that when it is operating that it will produce as per its warranted power curve.

The wind farm SCADA system and its reporting functions are key in assessing these contractual performance measures and in comparing the wind farms performance compared to its original budget.

The main key performance index (KPIs) for a wind farm are

- Turbine availability
- Operating efficiency (i.e., how well the turbines are producing compared to their warranted power curve)
- Budget deltas due to
  - Wind speed variations
  - Availability variations
  - Operating efficiency
  - Curtailment

Wind Farm Portfolios

Many organizations own and/or operate a portfolio of wind farms which may cover wide geographic areas or indeed countries. Operating strategies and infrastructure now need to reflect these larger organizations. Within in a portfolio, owners are likely to have wind farms of multiple turbine types which are of different ages and technologies. They need to have a way to view and report on these assets in a consistent manner.

In addition to a wind farm SCADA system, there is therefore a requirement to have a central portfolio management system. In addition to providing visibility, control and reporting of the wind farm portfolio, portfolio systems are likely to have to interface with enterprise resource planning systems to handle parts tracking, labor tracking and scheduling.

For utilities, there is likely to be a requirement to use or at least integrate with their existing systems.

Many portfolio owners operate a 24/7 central operations center. These will co-ordinate operations and maintenance across the portfolio. This will usually include managing safety and access control aspects of wind farms.

The scheduling and safety aspects will become increasingly important for offshore wind farms.

Wind Farm Operations

Larger wind farms will often be permanently staffed. Turbines have a program of scheduled maintenance, typically on a 6 month basis and combined with unscheduled maintenance these activities can justify a full-time presence. Smaller wind farms will be maintained by crews covering regions.

The wind farm SCADA systems are therefore accessed both locally at the wind farm and remotely. They also need to be accessed from within the wind farm as the traveling time between different parts of wind farms can be significant.

Forecasting

As wind-generated electricity increasingly impacts on many countries' grids, its variable nature makes a uniform approach to managing energy from all sources crucial. Accurate short-term forecasting of wind power can help to achieve this goal. Independent system operators who have to manage supply and demand on a grid system can avoid many of the balancing issues if accurate forecasts of wind output are available. Anybody trading in wind energy can negotiate a better price if they have precise information about the quantity they have to sell at any particular time.

The forecasting process involves four steps: First, forecasts of meteorological parameters for the wind farm area are obtained from numerical weather prediction providers; second, the weather input is refined to suit the wind farm site and sophisticated wind farm models run; third, detailed data from the wind farm are used to run auto-adaptive algorithms, which adjust the forecast to site-specific conditions; fourth, the client is provided with regularly updated site-specific forecasts of wind farm output delivered by e-mail, FTP or website. Typically, forecasts are updated hourly and each one contains 7-day predictions.

Forecasts are also used to schedule maintenance and downtime.

Wind farm SCADA systems typically act as data feeds to centralized forecasting services. Wind farm SCADA systems will be discussed next.

SCADA SYSTEMS IN WIND FARMS

SCADA Platforms

Historically, the wind farm SCADA systems were provided by the wind turbine manufacturers. These were implemented using either standard SCADA toolboxes or in many cases as bespoke applications.

Wind farms are strongly "typed" in that they have a large number of identical turbines and their meteorological masts and substations share many key attributes. They therefore suit a configuration driven application approach rather than building solutions from a toolbox on a per project basis. This is particularly the case for turbine manufacturers delivering turnkey systems as they have control over all the components of the wind farm. An example of SCADA control scheme is shown in Figure 64.7.

Many wind farm owners have preferred to have a SCADA solution from a third-party supplier. This can be for a number of reasons:

- Enhanced functionality (particularly for reporting)
- Data maintenance features
- Common interface for different turbine types
- Common reporting for different turbine types
- Independent measurement and reporting for contractual KPIs

Early third-party systems were able to interface to the turbine controllers but more recently, turbine manufacturers have only allowed access to turbine information via their own SCADA systems. This can be in the form of a real-time interface or a historical data interface (i.e., database of statistics and events).

Wind farm SCADA systems have used databases to store historical data. The databases used have changed over time and with the size of projects but most are open database connectivity compliant and most modern use MS SQL Server.

Wind Farm Communication Protocols

There are two main communication interfaces in wind farms for real time data:

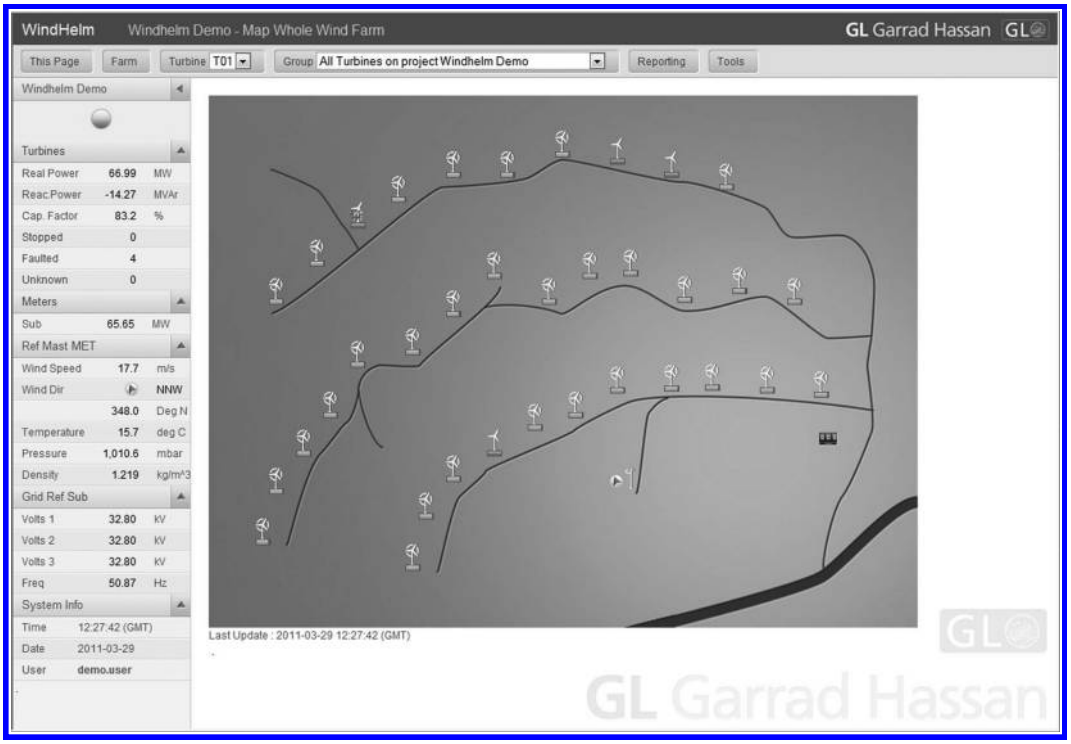
1. The interface with the turbine controller
2. The interface to the wind farm SCADA system

The turbine controller interfaces have historically used proprietary protocols which has complicated the wind farm SCADA integration process.

As the industry has grown, there has been an increase in the use of standard controller equipment and wider use of standard protocols such as Modbus TCP/IP.

However, more recently the turbine manufacturers have only allowed access to turbine information through a wind farm level interface. The de facto standard for these real-time interfaces has become OPC DA, with some vendors offering OPC DA XML.

In 2006, the IEC 61400-25 series of standard were published to try and establish a standard for communications with wind power plant. The series consists of the following standards:



Turbines		
Real Power	66.99	MW
Reac.Power	-14.27	MVAr
Cap. Factor	83.2	%
Stopped	0	
Faulted	4	
Unknown	0	
Meters		
Sub	65.65	MW
Ref Mast MET		
Wind Speed	17.7	m/s
Wind Dir		NNW
	348.0	Deg N
Temperature	15.7	deg C
Pressure	1,010.6	mbar
Density	1.219	kg/m^3
Grid Ref Sub		
Volts 1	32.80	kV
Volts 2	32.80	kV
Volts 3	32.80	kV
Freq	50.87	Hz
System Info		
Time	12:27:42 (GMT)	
Date	2011-03-29	
User	demo.user	

Last Update : 2011-03-29 12:27:42 (GMT)

FIG. 64.7
Implementation of SCADA in a typical wind farm.

- IEC 61400-25-1 ed1.0 (2006–12): Overall description of principles and models
- IEC 61400-25-2 ed1.0 (2006–12): Information models
- IEC 61400-25-3 ed1.0 (2006–12): Information exchange models
- IEC 61400-25-4 ed1.0 (2008–08): Mapping to communication profile
- IEC 61400-25-5 ed1.0 (2006–12): Conformance testing
- IEC 61400-25-6 ed1.0 (2010–08): Logical node classes and data classes for condition monitoring (not yet published)

These standards define information models and information exchange models and map them onto one of the following protocols:

- Simple object access protocol based web services
- OPC/XML-DA
- IEC 61850-8-1 MMS
- IEC 60870-5-104
- DNP3

The information exchange models in IEC 61400-25 allow for historical data access although this is not supported in all protocol mappings.

Data Maintenance

Real wind farm SCADA systems do not collect data for all times. Many periods of data loss are legitimate due to loss of power to the site. Turbines will also not collect data when they are powered off for scheduled or unscheduled maintenance. Depending on the system architecture, interruptions in communications may result in loss of data.

Different causes of data loss need to be allocated against differing parties for keeping track of contractual warranties and guarantees.

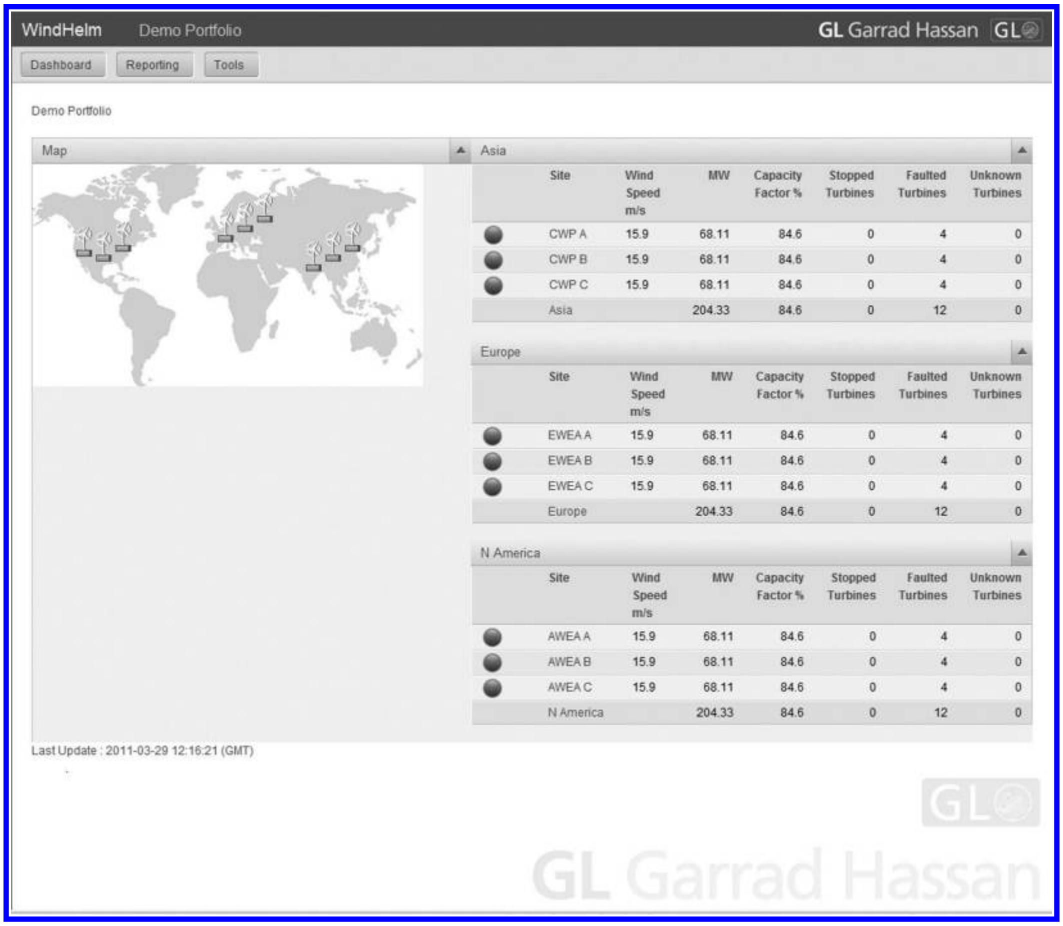
The party responsible for downtime can also not always be correctly determined automatically.

Regardless of the source of data loss or the reasons for incorrect allocations and however effectively they are minimized, it is a reality that they will occur. Wind farm SCADA systems therefore need to have facilities to maintain the data that is collected and allow data to be edited in a traceable way.

Condition Monitoring

In the past, it has been difficult to justify installing vibration-based condition monitoring equipment on wind turbines. The relatively large numbers of relatively low-value plant did not justify the expense. Wind turbines are also a harsher environment to install equipment than conventional thermal plant and have much less space. There are also challenges associated with the variable loading.

However, there is certainly value in being able to do condition based maintenance and all the current trends make condition monitoring increasingly attractive. Larger turbines have higher value production, are more expensive plant and require more expensive maintenance equipment. This is



Demo Portfolio

Asia

	Site	Wind Speed m/s	MW	Capacity Factor %	Stopped Turbines	Faulted Turbines	Unknown Turbines
●	CWP A	15.9	68.11	84.6	0	4	0
●	CWP B	15.9	68.11	84.6	0	4	0
●	CWP C	15.9	68.11	84.6	0	4	0
	Asia		204.33	84.6	0	12	0

Europe

	Site	Wind Speed m/s	MW	Capacity Factor %	Stopped Turbines	Faulted Turbines	Unknown Turbines
●	EWEA A	15.9	68.11	84.6	0	4	0
●	EWEA B	15.9	68.11	84.6	0	4	0
●	EWEA C	15.9	68.11	84.6	0	4	0
	Europe		204.33	84.6	0	12	0

N America

	Site	Wind Speed m/s	MW	Capacity Factor %	Stopped Turbines	Faulted Turbines	Unknown Turbines
●	AWEA A	15.9	68.11	84.6	0	4	0
●	AWEA B	15.9	68.11	84.6	0	4	0
●	AWEA C	15.9	68.11	84.6	0	4	0
	N America		204.33	84.6	0	12	0

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FIG. 64.8
Portfolio wind farm system covering a number of nations in Europe.

particularly true of offshore wind turbines where being able to plan maintenance has even larger benefits.

As condition-monitoring systems are installed, the wind farm SCADA systems act as a data source to provide status and environment information to the condition-monitoring systems and in some cases also act as a user interface for condition monitoring system (CMS) warnings.

Portfolio Systems

For portfolio systems, as exemplified in Figure 64.8, many larger organizations either develop their own system or integrate into an existing system. The use of historians, such as PI is common in utilities and larger operators and owners. Third-party solutions are available for smaller independent power producers.

Depending on the organizations requirements, portfolio systems can consist of only a reporting layer, retrieving historical data from wind farm SCADA systems.

Abbreviations

HV	high voltage
KPI	key performance index
MV	medium voltage
RTU	remote terminal unit

Symbols

P	power (W)
ρ	air density (kg/m^3)
A	swept area of rotor (m^2)
V	wind speed (m/s)
C_p	coefficient of power